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OPTIMIZATION OF ENERGY USAGE IN MILITARY FACILITIES (PHASE 1)

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Tyndall Air Force Base, Florida

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OPTIMIZATION OF ENERGY USAGE IN MILITARY FACILITIES (PHASE 1)

Department of the Army

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Champaign, Illinois

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AIR FORCE CIVIL ENGINEERING CENTER

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TYNDALL AIR FORCE BASE

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A computer model was developed for predicting hourly building thermal loads and simulating the response of heating and cooling systems to these hourly loads. The rigorous algorithms employed in the program permit determination of the effects of building and system design variables on energy consumption. The report presents results of the program application to a test case building at four sites.

SUMMARY

Conventional design methods for building heating and cooling systems are inadequate and usually result in oversized and inefficient systems. The US Army Construction Engineering Research Laboratory (CERL) has developed for the Air Force a computer model which predicts a building's hourly thermal load profile by using actual weather data, simulates the operation of heating and cooling systems in response to the predicted load, and determines the building's total energy consumption. The computer model determines the thermal load profiles by using a modified version of the National Bureau of Standards' Load Determining Program (NBSLD): it models system performance and determines building energy consumption by using a revised version of the system simulation portion (SYSSIM) of NASA's Energy Cost Analysis Program. A free format input and data-checking program was written to use with both NBSLD and SYSSIM. To complete the computer model, a weather tape decoding program was developed to produce a weather data tape suitable for input to NBSLD from the weather tapes supplied by the National Climatic Center.

Researchers used the computer model, as described above, to study the energy consumption of a particular Air Force building at four sites in the United States. Results of that study showed the energy consumption figures for that building, and effected formulation of several general conclusions about multi-zone and variable-volume heating systems.

The final form of the computer model, believed to be the best compromise between input requirements and accuracy of results, can be used by engineers having little computer experience.

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FOREWORD

This report is one of three documents concerning this work unit. The other documents are "Thermal Load Analysis and System Simulation Program User's Manual" and "Thermal Load Analysis and System Simulation Program Reference Manual. The work described by this report was performed by the U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, Illinois for the Civil Engineering Division of the Air Force Weapons Laboratory (AFWL), Kirtland AFB, NM, under AFWL Project Order No. AFWL 75-223. In March 1975 the responsibility for the work unit was transferred to the Air Force Civil Engineering Center (AFCEC), Tyndall AFB, FL. Mr. Doug Hittle was CERL's primary investigator. Lt. William J. Bierck was the AFWL project engineer and Mr. Freddie L. Beason, P.E., was the AFCEC project engineer.

Special thanks are extended to Dr. T. Kusuda of the National Bureau of Standards for providing a copy of the "NBSLD" program which was used as the basis for much of this work. Contributions of Mr. Ron Jensen of NASA's Langley Research Center are also gratefully acknowledged. The laboratory provided the "NECAP" program whose System Simulation Program (SYSSIM) was modified and used for this work. In addition to the authors, the efforts of A. Itzkowitz, B. Sliwinski, T. Fishman, and B. Lidral, all of the Construction Engineering Research Laboratory, contributed to the timely achievement of the research objectives.

This report has been reviewed by the Information Officer (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

During FY 75, CERL conducted research for the Air Force on energy optimization for military facilities. The project originated from recognition that conventional design methods, particularly estimating energy consumption of building heating and cooling systems, are inadequate, causing oversized equipment and overestimation of system energy consumption.

These errors are principally the result of steady-state assumptions associated with conventional building loads calculatory schemes. For example, a typical cooling load calculation assumes that the following states exist long enough to allow heat transfer to the space to reach steady state: the building is fully occupied, all lights are on, the outdoor temperature remains at the summer design high, and sunlight is continuous. For all but the lightest structures, these conditions must persist for several hours or perhaps days before steady state is achieved; in reality, this "worst case" can never occur. The oversized heating and cooling systems (30-50 percent excess in many instances) not only result in wasted first-cost expenditures, but frequently lead to high maintenance and operating costs caused by system short-cycling and poor part-load performance. Similarly, inaccurate estimates of a building's energy consumption can lead to inaccurate evaluation of various energy conservation options.

The principal objective of the FY 75 research was to develop a computer model having the capability of (a) predicting the hourly thermal load profile of a building from actual weather data, (b) simulating the operation of equipment systems in response to the predicted load, and (c) predicting the energy consumption of a building from the results of (a) and (b). There were two major reasons for developing a new computer model in the face of a host of existing programs. First, most load-predicting and systems simulation program combinations in the public domain were not sufficiently detailed and rigorous to precisely indicate the effects of changes in building and system design variables on energy consumption. Second, prospective users have rejected many rigorous and detailed programs because of their complex input requirements.

To achieve this objective, researchers used current computer codes when

possible, modifying them for error correction and more simplified use, and developing simplified input formats for each section. A user's manual and a program reference manual were prepared and energy use in a sample building was examined using the completed computer model.

The completed model is believed to be the best compromise between user input requirements and accuracy of results. The model can be used by air-conditioning engineers having little or no computer experience. Two significant problems requiring additional research are the program's large-core memory and its lengthy run-time requirements.

SECTION II

THE LOAD-PREDICTING PROGRAM

During development of a load-predicting computer program, numerous existing computer algorithms were investigated. The criterion used to evaluate these programs was the requirement that the program be sufficiently accurate to permit evaluation of changes in the parameters which affect energy usage in buildings. Existing hourly load-calculating programs are of two basic classes: those which perform interpolation based on calculated peak heating and cooling loads and those which perform detailed hourly calculations based on input parameters reflecting the building's structure.

The first class of programs is generally based on the steady-state equation for heat transfer:

$$Q = UA(\Delta T)$$

where Q = rate of heat loss or gain (Btu/hr)

U = heat transfer coefficient (Btu/hr sq ft °F)

A = Area (sq ft)

ΔT = temperature gradient (°F).

Using this equation and hourly temperatures read from weather tapes, the building transmission loss or gain is calculated by interpolation between the peak heating and cooling loads supplied by the user. Note that the assumption of steady state may only be satisfactory for load calculations in which the temperature difference between the ambient and the conditioned space is large compared to the daily variation in ambient temperature. This condition may occur during the winter in cold climates but is certainly not satisfied during the summer cooling season. In programs using this steady-state approach, the thermal capacitance of the building (an important parameter in estimating fluctuation of building heating and cooling loads) is completely ignored.

A further constraint to the accuracy of these programs is that the peak heating and cooling loads calculated by the user are frequently overestimated; as a result, the hourly interpolated values for load based on these inputs is

inaccurate. In addition, these programs frequently do not permit investigation of variable temperature within an air-conditioned space. Consequent study results indicate that this is a particularly important factor in analyzing the building load. These programs also typically treat solar heat gain as an instantaneous load, thereby linearly prorating the originally calculated solar gain on the basis of hourly incident solar radiation values. Note that solar radiation is first absorbed by objects in the space and is not manifested as a cooling load until those objects transfer the heat to the room air later. Thus, substantial error can be introduced by considering solar radiation as an instantaneous load. These programs generally have relatively short execution times; however, in view of the potential inaccuracies inherent in the various simplifying assumptions, this was not considered to be a significant advantage.

For all of these reasons, programs involving the simplified interpolative approach were discarded. (Note that a number of proprietary programs about which little information is available are believed to be in this class.)

The second class of programs typically calculates space heating and cooling loads by solving a set of heat balance equations for all interior surfaces, or by an approximate method in which each building element contributes to the space load through its own weighting factor. The significant feature of these programs is that *transient* heat conduction, radiation, and convection are treated rigorously and in detail. Steady state is not assumed, and the program, not the user, calculates heating and cooling loads. These programs account for building thermal capacitance, the delayed effect of sunlight through windows and on walls and the effects of window- and wall-shading. A general consequence of this more rigorous approach is that programs using this technique are sensitive enough to parameters affecting the loads to be useful for comparing different building construction and operating methods.

When this study was initiated, only two load-determining programs were generally available which could be classified as rigorous: the US Post Office program and the National Bureau of Standards Load Determining (NBSLD) program (ref. 1). The principal difference between these programs is that the Post

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1. Kusuda, T., NBSLD, Computer Program for Heating and Cooling Loads in Buildings, National Bureau of Standards, Washington, DC, November 1974.

Office program uses a weighting factor approach (ref. 2) to approximate transient heat transfer, while the NBSLD program employs a more rigorous response factor and heat balance approach (ref. 1 & 3). Both programs were used and evaluated in this study, and the NBSLD program was selected as the basis for the final load-determining program because of its more rigorous algorithms and less complicated input data requirements. Some execution speed was sacrificed for improved program sensitivity. Another important consideration was that portions of the NBSLD program have been validated by carefully controlled experiments (ref. 4).

After program selection, the original language (Univac compatible FORTRAN) was converted to CDC compatible FORTRAN, certain critical program corrections were made, and several subprograms were restructured to eliminate superfluous code and improve clarity. In addition, the solar heat gain calculation procedures were changed to permit use of measured hourly incident solar radiation data, rather than the cloud-cover modifier approach which was based on the observed amount and type of cloud cover. The room humidity calculation procedure was changed to more accurately simulate the varying room humidity occurring during the cooling season. A number of changes were implemented to permit interfacing of the systems simulation program (Section IV).

A free-format input and data-checking program was implemented when it became apparent that input data errors were difficult or impossible to discover until lengthy program execution produced suspicious results. A more logical data input sequence was also necessary. The new input data processing program provides a user-oriented, free-format input form based on the use of keywords. It is capable of checking all input data against reasonable upper and lower bounds and terminating execution with appropriate error messages if fatal input errors were encountered. Note that termination is not normally concurrent with

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2. Procedure for Determining Heating and Cooling Loads for Computerizing Energy Calculations, ASHRAE, New York, NY, 1975.

3. Kusuda, T. "Thermal Response Factors for Multi-Layer Structures of Various Heat Conduction Systems," ASHRAE Trans., Vol 73, Part 1, 1969, pp 746-271.

4. Burch, D. M., et al, "Experimental Validation of the NBS Load and Indoor Temperatures Prediction Method," ASHRAE Trans, Part 2, 1974.

the first input error; the program usually scans the entire input deck and records all discovered errors before terminating. Thus, debugging of input data can usually be accomplished in one pass.

SECTION III

THE INTERFACE PROGRAM

The load-determining program generally performs calculations in a sequential fashion; that is, the hourly loads of one room or zone are calculated for the entire period of interest before the program calculates loads for the second room or zone. This feature is useful because the effects of changes in one room or zone on load can be determined without re-calculating the hourly loads for unchanged zones. However, to simulate the performance of mechanical equipment serving multiple zones, the loads must be made available to the simulation program in a parallel fashion; i.e., the loads for all zones for the first hour must be sequentially followed by the loads for all zones for the second hour, and so on, for the period simulated.

To achieve this parallel simulation, researchers developed an interface program (SYSPREP) to prepare an input file for the system simulation program from the load-determining program output file. Depending on the number of days and the number of zones being simulated, the output file from the load-determining program and therefore the execution time required by SYSPREP can be lengthy. For this reason, the overall program was structured so that any number of system simulations can be made for a particular building with only one SYSPREP execution.

SECTION IV

THE SYSTEM SIMULATION PROGRAM

The hourly space loads calculated by the NBSLD program are not generally those experienced by the building heating and cooling systems. The calculated space loads are minimums which are exceeded to varying degrees because of ventilation requirements and control system and equipment inefficiencies. Thus, energy consumed by heating and cooling systems must be calculated by simulating system performance in response to building space loads, which in turn requires a systems simulation program. Currently used system simulation programs were reviewed and found to employ either simplified approximate or detailed rigorous methods. Again, the simplified approaches were rejected because they were insensitive to changes in type of fan system, type of control, and other design variables.

Only one rigorous systems simulation program was available in the public domain. This program, a part of NASA's "NECAP" (NASA's Energy Cost Analysis Program) was developed at the Langley Research Center. The systems simulation portion of NECAP (SYSSIM) is based on "ASHRAE Proposed Procedures for Simulating the Performance of Components and Systems for Energy Calculations" (ref. 5). The program performs three key functions:

a. Air distribution requirements are determined based on peak heating and cooling requirements.

b. Each distribtuion system is simulated as it responds to hourly space loads and the demands on chillers and boilers are determined.

c. Determination of the building's hourly, monthly, and annual demand for all forms of energy and fuel is based on the load-varying, operating characteristics of energy-consuming equipment.

The SYSSIM program was selected as the basis for the system simulation portion of the overall program because its program features were identical to those required to meet the system simulation objectives of this work effort and because it uses rigorous methods.

5. Proposed Procedures for Simulating the Performance of Components and Systems Energy Calculations, Second Edition, W. F. Stoecker, editor, ASHRAE, New York, NY, 1971.

Modifications to the SYSSIM program included correction of certain critical errors, development of an input data reading and checking program, and addition of equipment component simulation routines to permit consideration of packaged, air-cooled, reciprocating chillers. Table 1 summarizes the energy distribution and conversion systems included in the program. The Program User Manual provides detailed descriptions of these systems and their various control options.

TABLE 1.

ENERGY DISTRIBUTION AND CONVERSION
SYSTEMS SIMULATED

Distribution Systems

1 - Single-Zone Fan Systems with Face and By-Pass Dampers

2 - Multi-Zone Fan System

3 - Dual-Duct Fan System

4 - Single-Zone Fan System with Sub-Zone Reheat

5 - Unit Ventilator

6 - Unit Heater

7 - Floor Panel Heating

8 - Two-pipe Fan Coil System

9 - Four-pipe Fan Coil System

10 - Two-Pipe Induction Unit Fan System

11 - Four-Pipe Induction Unit Fan System

12 - Variable Volume Fan System with Optional Reheat

13 - Constant Volume Reheat Fan System

Cooling Plants

1 - Hermetic Reciprocating Chiller

2 - Hermetic Centrifugal Chiller

3 - Open Centrifugal Chiller

4 - Steam Absorption

5 - Open Centrifugal with Steam Turbine

6 - Reciprocating Air-Cooled Package Chiller

TABLE 1. (Concluded)

Heating Plants

1 - Hot Water or Steam Boiler

Generating Plants

1 - Engine-Generator

SECTION V

WEATHER TAPE DECODING PROGRAM

Both the load-determining program and the systems simulation program require input of hourly weather data. This data is available on computer tape for many sites throughout the country from the National Oceanic and Atmospheric Agency, Asheville,NC. To use this data, weather tapes must be read, decoded, and transformed into weather files which can be input to the load-determining program.

To accomplish the weather tape decoding task a program was written which reads the appropriate data from the 1440 series weather tapes (hourly climatological data) and from the 280 series tapes (hourly solar data), thus providing a new weather data file hourly. This program also checks each record to determine that the weather parameter values are within reasonable bounds and prints a message when bad daily weather records are encountered. The decoding program can operate with or without solar data tapes (280 series); if solar data is not available, the load program calculates solar radiation from clear-sky calculated radiation and a cloud-cover modifier by reading cloudiness observations reported on the climatological data tapes (1440 series).

A second, optional weather program can be used to "file in" weather data for days missing on the 1440 series climatological data tapes. The program simply substitutes data from the previous day for that which is missing.

SECTION VI

OVERALL PROGRAM STRUCTURE

Review of how each element contributes to the overall program is best accomplished by considering the steps of the process used to obtain the desired final results. Figure 1 illustrates the overall flow of the program. The first step is usually the processing of National Climatic Center weather tapes for a particular site or sites using the weather tape decoding program. The user can review the printed output from this run and determine whether the weather data processing program should be executed to fill in data for days missing on the original tape.

The user then codes the input dat for the building to be studied and executes the load-determining program (NBSLD). Execution in the design mode without weather data will determine the peak heating and cooling loads, and with the addition of the ventilation loads, will determine the required boiler and chiller capacities. Note that this design load calculation is based on daily temperature and solar profiles generated by the program from input design temperatures; it is *not* a steady-state simplified approach. Peak calculated loads will therefore generally be lower than those predicted by steady-state calculations.

The next step is execution of the load-determining program, using actual weather data for the desired period (usually 1 year) to create an output file containing hourly loads and weather data.

The output file is then processed by executing the SYSPREP program to rearrange its contents for subsequent use by the systems simulation program.

The user next prepares the input deck, describing the various systems components to be simulated, and then executes the systems simulation program (SYSSIM). SYSSIM, using the hourly data file created by SYSPREP, can be executed any number of times to investigate the effects on energy consumption of changes in system type, capacity, and method of control. The printed output from SYSSIM is a summary of monthly and annual energy consumption.

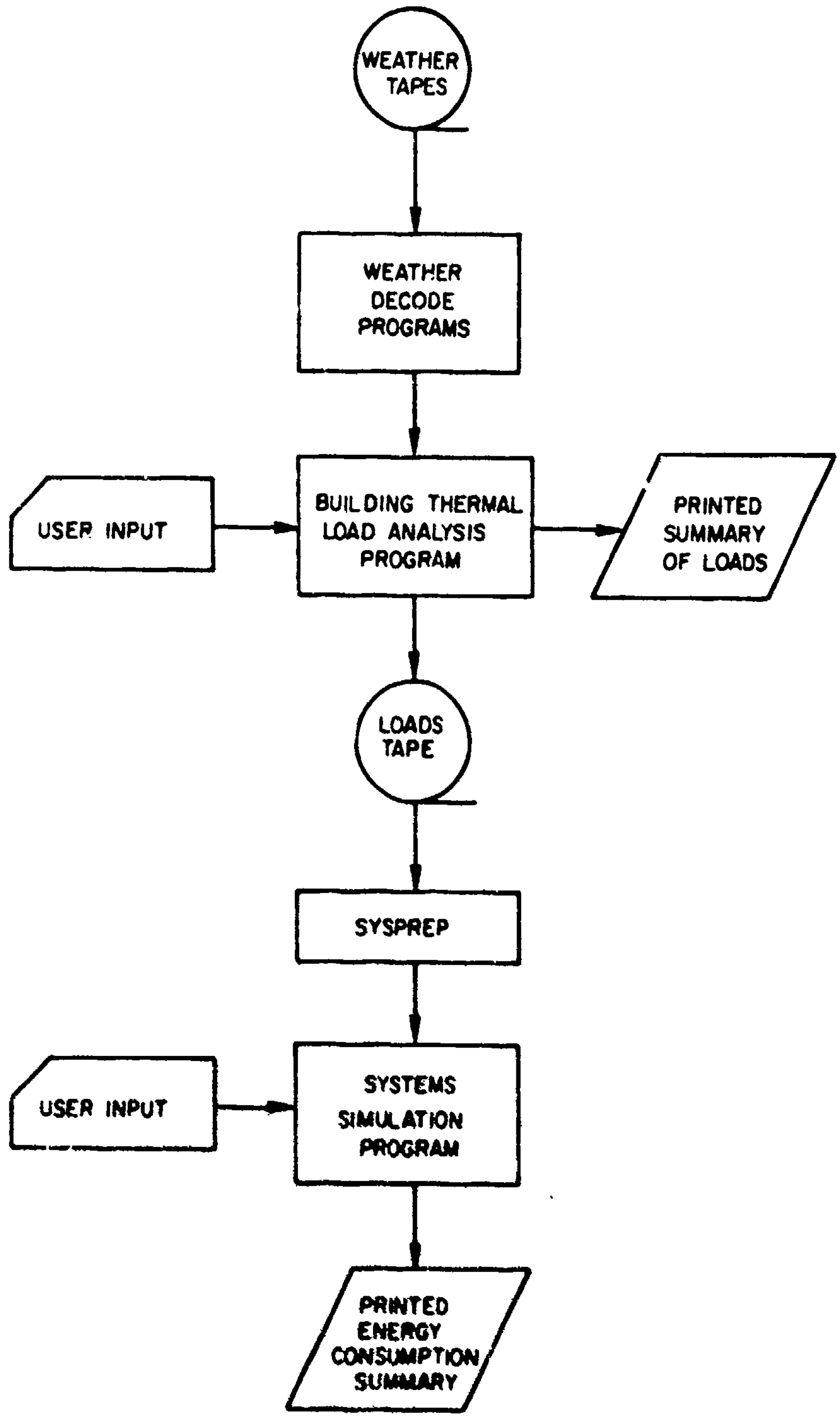


Figure 1. Program Flow Chart

SECTION VII

PROGRAM DOCUMENTATION

In addition to the modification and development of the previously described programs, researchers conducted two major program documentation efforts. The first resulted in a Program User's Manual which describes the card and tape data inputs required to execute the building load-predicting and system simulation programs. This manual contains pertinent tables reprinted from various sources and a complete sample problem which provides the card input data and the resultant output from a design day and one-year simulation study. This manual, based on considerable experience in the use of these programs, is designed to permit effective use of the programs without a detailed knowledge of computer systems or the program code.

The second documentation effort produced a Program Reference Manual for computer programmers and engineers interested in the details of the program algorithms and their implementation in computer code. This document contains a general description of the program, a list of input, output, and common variables, an English-language flow chart, and a detailed description of the calculation sequence for each main program and subroutine. This effort reflects the first time that a complex, lengthy, load-predicting and system simulation program has been completely documented. This documentation not only provides information required by maintenance personnel who will maintain program software but its preparation revealed numerous critical coding errors and program inefficiencies.

SECTION VIII

APPLICATION OF THE LOAD-PREDICTING AND SYSTEM SIMULATION PROGRAM

In addition to the development efforts previously described, the l: -ore-dicting and system simulation programs were executed to illustrate the usefulness of the programs and to evaluate certain heating and cooling system options.

The Air Force selected a flight training facility at Tyndall Air Force Base, FL (Building 548) as a test structure. The two-story building has an insulated, built-up roof; its exterior walls are prestressed concrete "T" panels with exposed fins, backed by either 6-in. concrete blocks, or by studs, insulation, and gypsum board. The facility contains no windows, so the only exposed glass areas are the exterior doors. The ground-level floor is a 4-in. concrete slab on-grade, covered with vinyl asbestos tile; the second-level floor is prestressed concrete "T" panels covered with a 2-in. concrete slab and vinyl asbestos tile. Interior partition walls are primarily either 6-in. concrete blocks, or gypsum board and studs.

Building 548 was modeled as ten separate zones, as shown in Figures 2 and 3. To facilitate modeling, two simplifications were made. First, researchers analyzed the heat-transfer characteristics of the exposed exterior fins, which showed that the overall fin effectiveness was approximately 1 (the ratio of the total heat loss from an exterior wall including the fins to the total heat loss from the same exterior wall without the fins). Thus, the only effect of the external fins was to increase the mass available for thermal storage. This effect was accounted for by assuming the wall thickness to be uniform and by adjusting its density to include the total mass. Second, the internal mass within each zone was accounted for as follows: any wall which is completely internal to a particular zone will essentially contribute only to the mass storage of thermal energy for the building. Therefore, the effect of these walls was accounted for by finding the total mass of all such walls for each story and by adding a layer of constant thickness, infinite conductivity, and appropriate density to the floor construction data for that story.

Lighting, occupancy, and room temperature schedules were derived from data supplied by the Air Force. The building was assumed to be fully occupied and fully lighted between 0700 and 1600 on weekdays; for one hour before and after this time, the building was assumed to be half-occupied and half-lighted. At

all other times, the building was assumed to be unlighted and unoccupied. Two distinct room temperature profiles were used: the first was a single, set-point thermostat schedule which controlled each zone at a constant of 75°F: the second was a dual, set-point thermostat schedule having night and weekend setbacks. With this scheduling system, each zone is cooled when its temperature rises above 78°F and heated when it drops below 68°F between 0700 and 1700 on weekdays. At all other times the temperature in each zone is allowed to float between 85°F and 60°F.

The Air Force selected four geographical locations for modeling: Charleston, SC; Fort Worth, TX; Phoenix, AZ; and Bismarck, ND. A "typical" weather year was selected for each site from weather tapes obtained from the National Climatic Center. The "typical" year chosen was that having the smallest annual sum of the deviations between the monthly mean temperature and the long-term monthly mean temperatures. For the four sites, the "typical" years chosen were: Charleston--1953, Fort Worth--1955, Phoenix--1961, and Bismarck--1960.

Execution of the load-determining program required use of the construction data for Building 548, the "typical" year weather data for each location, and both the single set-point and the dual set-point room thermostat schedules. The output (both the hourly data and the annual heating and cooling load for Building 548) was obtained for each location and each temperature-control schedule, exclusive of the load caused by ventilation air. These results (summarized in Table 2) illustrate the advantage of the dual set-point thermostats over the single set-point thermostats; both the heating and cooling loads were reduced in all locations when the dual set-point schedule was used. Note that the amount of actual savings cannot be determined until ventilation air heating and cooling loads are included and equipment and system inefficiencies are considered.

Using the hourly data generated by the load-determining program, researchers analyzed six air-conditioning (heating and cooling) systems at each location with the system simulation program SYSSIM. These air-conditioning systems, prescribed by the Air Force, included both multi-zone fan systems and variable volume fan systems. All were assumed to have one electrically powered, air-cooled reciprocating chiller and one gas-fired boiler, both with year-round availability. Sizing of the boiler and chiller at each location was based on both the heating and the cooling requirements of the individual

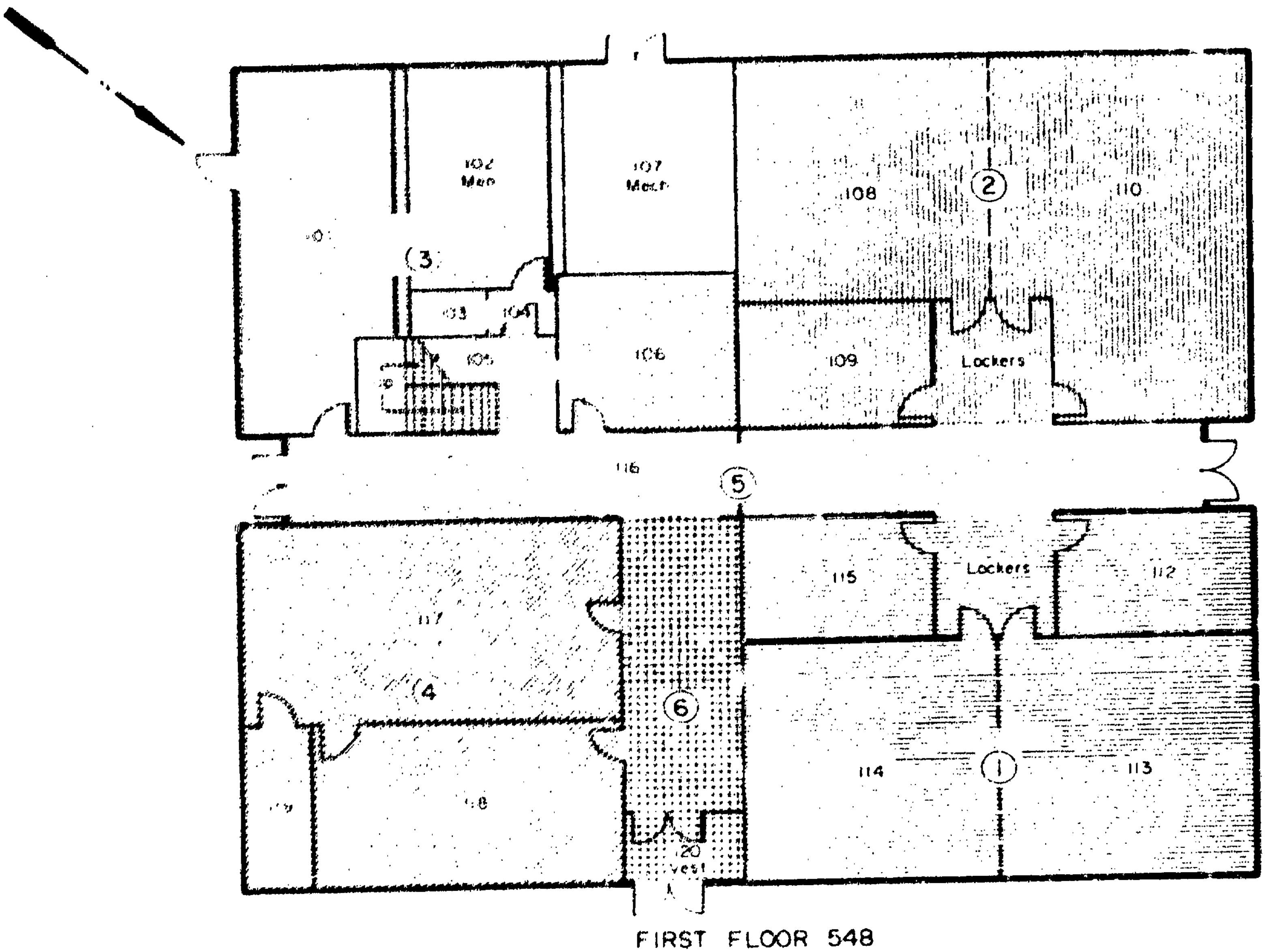
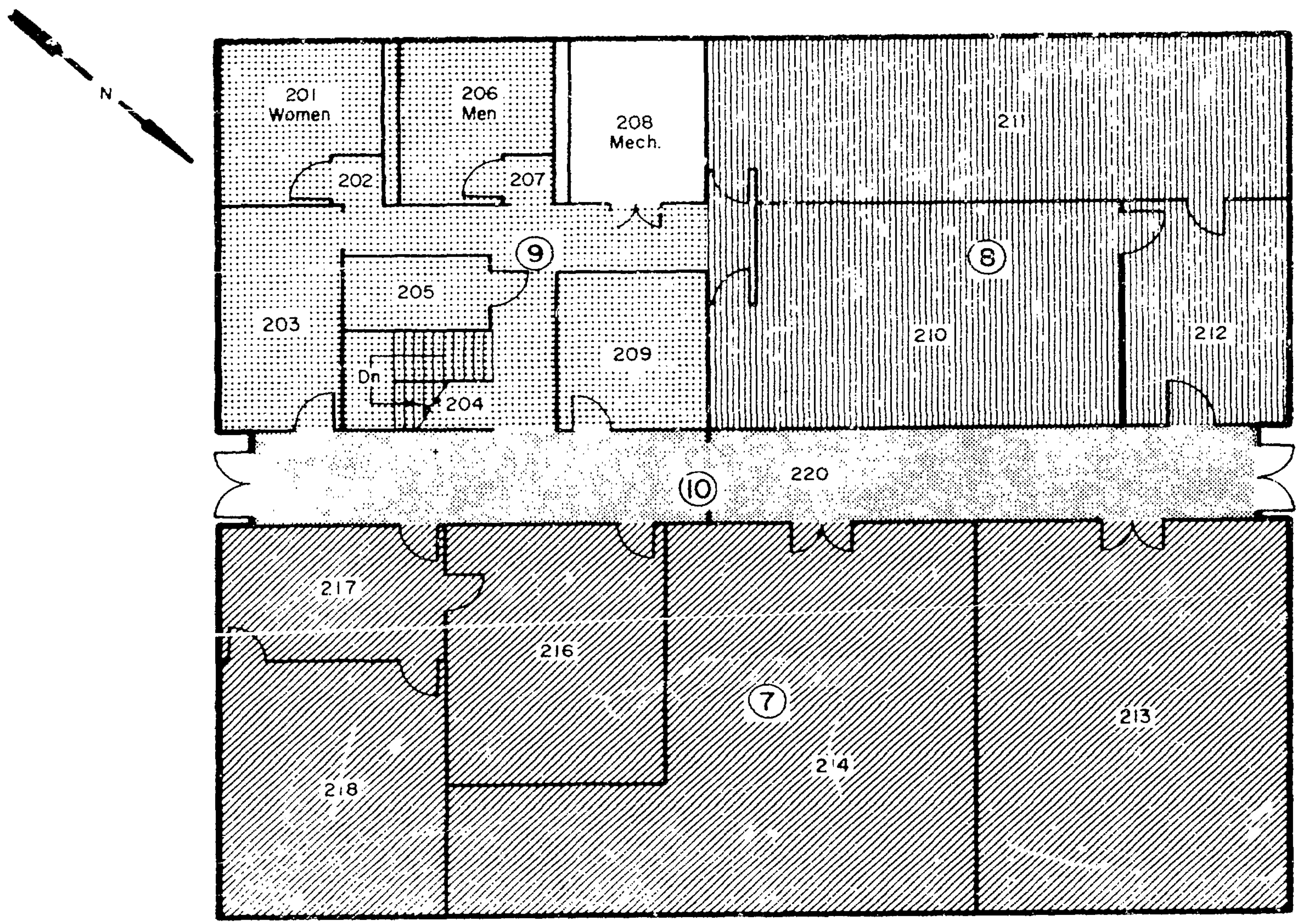


Figure 2. First-Floor Plan Flight Training Center



SECOND FLOOR 548

Figure 3. Second-Floor Plan Flight Training Center

TABLE 2.

ANNUAL HEATING AND COOLING LOADS FOR BUILDING 548 IN FOUR LOCATIONS

(Loads in Million Btu's)

	Location			
Load*	Charleston	Fort Worth	Phoenix	Bismarck
Heating, Single Set-Point Thermostats	397.92	326.59	283.89	1229.1
Heating, Dual Set-Point Thermostats	70.07	60.41	33.17	681.91
Cooling, Single Set-Point Thermostats	344.75	435.32	487.99	120.52
Cooling, Dual Set-Point Thermostats	193.40	251.73	301.86	58.92

* This load does not include loads from ventilation air.

building, as determined by a design-day run from the load-determining program with the addition of the ventilation air heating and cooling requirements. Table 3 provides boiler and chiller capacities for each building. Two air-handling units were assumed--one for each floor--and all systems were assumed to have no humidity control. Table 4 shows other characteristics commom to all systems; characteristics relevant to individual systems are described below:

a. System 1--Multi-zone Fan System With Single-Point Thermostats and No Economy Cycle. This system maintains all zones at a constant 75°F, with the air-handling systems operating continuously. With no economy cycle, a fixed minimum amount of outside air is mixed with return air and supplied to the air-handler.

b. System 2--Multi-zone Fan System With Dual-Point Thermostats and No Economy Cycle. This system is similar to System 1, except that each zone's temperature is controlled by the dual-point temperature schedule. Each air-handling system shuts off if the total sensible load on that system, exclusive of ventilation air loads, is zero. When the air-handlers are operating, the minimum amount of outside air is introduced into each system.

c. System 3--Multi-zone Fan System With Dual-Point Thermostats and Temperature Economy Cycle. This system differs from System 2 only in the amount of outside air introduced to the air-handlers for ventilation. With the temperature-controlled economy cycle, the amount of ventilation air introduced to an air-handler depends on the relationships between the return-air temperature, the outside-air temperature, and the desired delivery-air temperature from the air handler which, for this cycle, is essentially the cold-deck temperature. For example, if the return-air temperature is less than the outside-air temperature, then the amount of outside air introduced will be the minimum allowed; if the outside-air temperature is less than the return-air temperature, but greater than the desired delivery air temperature (cold-deck temperature), then 100 percent outside air will be introduced. Finally, if the desired delivery air temperature is greater than the outside air temperature, but less than the return-air temperature, outside and return air will be introduced in proper proportion to maintain the desired delivery air temperature.

d. System 4--Multi-zone Fan System With Dual-Point Thermostats and Enthalpy-Temperature Economy Cycle. This system is similar to System 2, except for the ventilation air control, which is based on both enthalpy and temperature

TABLE 3.

BOILER AND CHILLER CAPACITIES FOR EACH LOCATION

	Charleston	Fort Worth	Phoenix	Bismarck
Boiler (Btu/hr)	333,000	343,000	275,000	636,000
Chiller (Tons)	34.3	35.6	32.4	24.4

TABLE 4.

CHARACTERISTICS OF ALL SYSTEMS AS MODELED

Minimum Outside Air:*	1st Floor - 1800CFM	2nd Floor - 1300CFM
Exhaust Air:*	1st Floor - 1500CFM	2nd Floor - 1300CFM
Total Supply Fan Pressure:	1st Floor - 2.72 in. H_2O	2nd Floor - 2.49 in. H_2O
Total Exhaust Fan Pressure:	1st Floor - .60 in. H_2O	2nd Floor - .52 in. H_2O
Min. Part Load Chiller Cutoff:	10%	
Chilled-Water Pump Head:	45.0 ft	
Boiler-Water Pump Head:	30.0 ft	
Fan and Pump Motor Efficiency:	85%	
Chilled Water Temp. Leaving Chiller:	42°F	
Fixed, Cold-Deck Temperature:**	55°F	
Hot-Deck Reset Schedule: *,**	Outside Dry Bulb Temp.	Hot Water Temp.
	40°F	130°F
	70°F	73°F

* Does not apply to variable-volume systems
** Does not apply to multi-zone systems where hot- and cold-deck temperatures are controlled by zone requirements.

differences between return air and outside air. If the enthalpy of the outside air is less than the return-air enthalpy, the temperature economy cycle is allowed to operate; otherwise, the quantity of outside air delivered to an air-handler will be the minimum allowed for that air-handler.

e. System 5--Variable Volume Fan System With Dual-Point Thermostats and Enthalpy-Temperature Economy Cycle. The air-handlers for this system supply air at 55°F. When the zone cooling load is maximum, the variable volume boxes allow maximum air flow to the zone. As the zone cooling loads decrease, the air flow decreases in proportion to the load reduction. The minimum air flow rate allowable is 10 percent of the maximum. If less cooling is required than that supplied at minimum air flow, or if heating is required, gas-fired reheat coils are used. Note that for any heating load, air flow is minimum; also, reheat coils can only heat the air to 125°F. Zone temperatures are controlled according to the dual-point temperature schedule, and the enthalpy-temperatures economy cycle functions as described previously.

f. System 6--Variable Volume Fan System With Dual-Point Thermostats, Enthalpy-Temperature Economy Cycle and Baseboard Heaters. This system is essentially like System 5 except that hot water baseboard heat is added to each zone. The hot water reset schedule of Table 4 was revised for this system to allow efficient operation of the baseboard heaters. The hot water schedule is 73°F hot water at 60°F outside-air temperature, and 140°F hot water at 35°F outside-air temperature. Baseboard heaters are assumed to function as long as the outside-air dry bulb temperature is below 60°F. The baseboard heaters were sized for each zone and location on the basis of the peak individual load shown by the load-predicting program design-day calculations. The heat output/lin ft of baseboard heater at design conditions is assumed to be 1000 Btu/hr; Table 5 provides the linear feet for each zone at each location.

In addition to the six systems selected by the Air Force and modeled in all four locations, two additional systems were modeled for Bismarck and Charleston. Features of each system are described below:

g. System 7--Multi-zone Fan System With Dual-Point Thermostats, Enthalpy Economy Cycle, and Hot- and Cold-Deck Temperature Control. This system differs from System 4 only in the hot- and cold-deck temperature control methods. For this system, the hot-deck temperature at a particular hour is determined by the zone requiring the warmest supply air temperature. The cold-deck temperature

TABLE 5.

LINEAR FEET OF BASEBOARD HEAT FOR EACH ZONE AND LOCATION

(For Variable Volume System With Baseboard Heat Only)

	Location			
Zone	Charleston	Phoenix	Fort Worth	Bismarck
1	7.6	4.7	5.9	15.4
2	12.2	8.5	10.9	24.9
3	27.7	21.5	27.8	56.5
4	6.2	4.0	5.0	12.6
5	8.6	6.4	8.3	17.6
6	5.3	4.0	5.1	10.8
7	19.6	16.2	21.0	40.2
8	14.0	11.6	15.0	28.7
9	29.6	24.3	31.5	60.5
10	9.6	7.9	10.2	19.5

is determined by the zone requiring the coldest supply air temperature.

h. System 8--Multi-zone Fan System Model of Present Heating and Cooling System in the Building. This system model approximates the air-conditioning system in the actual building. This system has dual-point thermostats, no economy cycle, and air-handlers which shut off if there is no sensible load. The system contains a 300-MBH, gas-fired boiler and a 39.3 ton air-cooled reciprocating chiller, both with year-round availability. The hot-deck reset schedule was set to provide 90°F water with outside temperature of 35°F, and 70°F water with outside temperature of 73°F. Other parameters for this system are the same as those shown in Table 4.

The SYSSIM output for the various system models and locations described above contains monthly and annual summaries of the loads felt by each system and the power consumed by the building. The load summaries include the total monthly and annual loads as well as the monthly peak load felt by each chiller and boiler. Also included are the monthly and annual summaries of the total and peak loads which the boilers and chillers could not meet; the monthly and annual summaries of loads which the air-handling system could not meet in each zone; and the peak zone heating and cooling loads not met in each month. The building's electrical consumption figures included monthly and annual summaries of the consumption and peak demand per month for lighting, cooling, heating, and fans. Gas consumption figures included monthly peak demand and monthly and annual consumption figures for heating.

Tables 6 - 9 and Figure 4 summarize the results of the various system simulation for each location. The SYSSIM output for all systems facilitates comparison of system performance characteristics. Two levels of comparison are possible. First, general performance characteristics of all systems can be determined from the data supplied for the four locations. Second, from the data supplied for each location, the "best system" for that location can be determined. The "best system" will, of course, depend on the criteria used for selection and must be a trade-off between power consumed, power cost, initial equipment cost, and ventilation requirements. Performance characteristics of the various systems are described below:

The multi-zone fan system with single set-point thermostats and no economy cycle (System 1 of Figure 4) proved to be the least efficient system in terms of loads felt by the systems as well as power consumption for heating and

TABLE 6.

SYSTEM SIMULATIONS FOR PHOENIX

ANNUAL SUMMARIES OF LOADS AND ENERGY CONSUMPTION

Electrical Consumption for Lighting (kWh): 89654.2

ANNUAL SUMMARY OF: / SYSTEM	Multi-zone Fan System With Single-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and Temperature Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and Enthalpy-Temperature Economy Cycle.	Variable Volume Fan System With Dual-Point Thermostats, Reheat Coils, Baseboard Heat, and Enthalpy-Temperature Economy Cycle.	Variable Volume Fan System With Dual-Point Thermostats, Reheat Coils, Baseboard Heaters, and Enthalpy-Temperature Economy Cycle.
Total Energy Consumption for the Bldg ($Btu/10^6$)	1406.4	1126.7	1166.9	1163.8	699.2	730.9
Electrical Consumption for Cooling (kWh)	154058.3	89876.1	67886.5	67780.5	69957.6	69962.0
Electrical Consumption for Fans (kWh)	44729.6	26906.5	26906.5	26906.5	11354.9	11354.9
Gas Consumption for Heating (Therms)	9736.2	4639.6	5192.2	5164.5	975.0	1292.3
Boiler Output (Btu/1000)	778898.3	323171.8	415376.0	413163.4	7800.8	103181.7
Boiler Load Not Met (Btu/1000)	11605.	156.	15099.	15099.	0.	0.
Peak Boiler Load Not Met (MBH)	65.	38.	85.	65.	0	0.
Zone Heating Load Not Met (Btu/1000)	14208.	8.	8.	8.	1727.	[illegible]41.
Chiller Output (Btu/1000)	1088218.4	614926.9	425266.0	423734.[illegible]	419276.7	419280.7
Chiller Load Not Met (Btu/1000)	0.	11.	151.	11	68	68
Peak Chiller Load Not Met (MBH)	0.	11	44.	11	18	18
Zone Cooling Load Not Met (Btu/1000)	0	0	0	0	0	19[illegible]88

TABLE 7.

SYSTEM SIMULATIONS FOR FORT WORTH

ANNUAL SUMMARIES OF LOADS AND ENERGY CONSUMPTION

Electrical Consumption for Lighting (kWh): 90363.0

ANNUAL SUMMARY OF: / SYSTEM	Multi-zone Fan System With Single-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and Temperature Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and Enthalpy-Temperature Economy Cycle.	Variable Volume Fan System With Dual-Point Thermostats, Reheat Coils, and Enthalpy-Temperature Economy Cycle.	Variable Volume Fan System With Dual-Point Thermostats, Reheat Coils, Baseboard Heat, and Enthalpy-Temperature Economy Cycle.
Total Power Consumption for the Bldg (Btu/10^6)	1887.1	1307.5	1349.2	1341.2	695.9	740.6
Electrical Consumption for Cooling (kWh)	126748.8	86460.5	59182.2	58442.0	57978.8	57981.3
Electrical Consumption for Fans (kWh)	36631.9	23066.3	23066.3	23066.3	9807.9	9807.9
Gas Consumption for Heating (Therms)	9983.9	6026.4	7374.7	7319.0	1335.2	1781.9
Boiler Output (Btu/1000)	798709.6	482109.6	589972.6	585517.0	106818.2	142548.2
Boiler Load Not Met (Btu/1000)	738.	2.	77.	77.	0.	0.
Peak Boiler Load Not Met (MBH)	43.	2.	32.	32.	0.	0.
Zone Heating Load Not Met (Btu/1000)	35176.	3.	3.	3.	7847.	2770.
Chiller Output (Btu/1000)	850090.4	623182.4	411664.3	403026.9	375576.1	375611.3
Chiller Load Not Met (Btu/1000)	0.	0.	0.	0.	0.	0.
Peak Chiller Load Not Met (MBH)	0.	0.	0.	0.	0.	0.
Zone Cooling Load Not Met (Btu/1000)	0.	0.	0.	0.	0.	13872.

TABLE 8.

SYSTEM SIMULATIONS FOR BISMARCK

ANNUAL SUMMARIES OF LOADS AND ENERGY CONSUMPTION

Total Consumption for Lighting (kWh): 90363.0

ANNUAL SUMMARY OF: / SYSTEM	Multi-zone Fan System With Single-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and Temperature Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats, Enthalpy-Temperature Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats, Enthalpy-Temperature Economy Cycle, and Hot and Cold Reset Control.	Variable Volume Fan System With Dual-Point Thermostats, Reheat Coils, and Enthalpy-Temperature Economy Cycle.	Variable Volume Fan System With Dual-Point Thermostats, Reheat Coils, Baseboard Heat, and Enthalpy-Temperature Economy Cycle.
Total Power Consumption for Building ($Btu/10^6$)	3531.1	2774.9	2841.4	2840.0	2358.0	924.7	1375.8
Electrical Consumption for Cooling (kWh)	68120.8	50477.5	17242.4	17201.4	15797.4	15962.2	15984.1
Electrical Consumption for Fans (kWh)	35604.5	26456.3	26456.3	26456.3	26456.3	11389.1	11389.1
Gas Consumption for Heating (Therms)	28265.9	21618.4	23417.7	23404.7	18632.5	4808.3	9318.1
Boiler Output (Btu/1000)	2,261,273.6	1,729,472.2	1,873,414.2	1,872,380.0	1,490,602.6	384662.6	745447.6
Boiler Load Not Met (Btu/1000)	878.	45.	45.	45.	46.	0.	0.
Peak Boiler Load Not Met (MBH)	66.	45.	45.	45.	46.	0.	0.
Zone Heating Load Not Met (Btu/1000)	42426.	5328.	5328.	5328.	0.	301472.	109191.
Chiller Output (Btu/1000)	444793.1	319208.7	78541.3	78000.2	50056.	69105.9	69206.3
Chiller Load Not Met (Btu/1000)	0.	0.	0.	0.	0.	0.	0.
Peak Chiller Load Not Met (MBH)	0.	0.	0.	0.	0.	0.	0.
Zone Cooling Load Not Met (Btu/1000)	0.	0.	0.	0.	0.	0.	26686.

TABLE 9.

SYSTEM SIMULATIONS FOR CHARLESTON

ANNUAL SUMMARIES OF LOADS AND ENERGY CONSUMPTION

Electrical Consumption for Lighting (kWh): 90008.6

ANNUAL SUMMARY OF / SYSTEM	Multi-zone Fan System With Single-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and No Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats and Temperature Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats, Enthalpy-Temperature Economy Cycle.	Multi-zone Fan System With Dual-Point Thermostats, Enthalpy-Temperature Economy Cycle, and Hot and Cold Reset Control.	Multi-zone Fan System as Is Present System in Building.	Variable Volume Fan System with Dual-Point Thermostats, Reheat Coils, Enthalpy-Temperature Economy Cycle.	Variable Volume Fan System with Dual-Point Thermostats, [illegible] Baseboard Heat, and [illegible] Temperature Economy Cycle
Total Power Consumption for Building (Btu/10⁶)	1890.0	1206.2	1257.7	1262.2	849.5	1015.6	[illegible]	[illegible]
Electrical Consumption for Cooling (kWh)	126768.3	78928.5	57530.2	56761.9	43183.1	65731.4	52447.7	[illegible]
Electrical Consumption for Fans (kWh)	35342.2	19843.5	19843.5	19843.5	19843.5	19843.5	8534.6	[illegible]
Gas Consumption for Heating (Therms)	10074.6	5399.3	6824.2	6715.3	3052.2	3943.1	1470.9	[illegible]
Boiler Output (Btu/1000)	805968.8	431942.1	545933.7	537222.9	244175.1	315498.3	117596.3	[illegible]
Boiler Load Not Met (Btu/1000)	1456.	3.	72.	72.	0.	0.	0.	0.
Peak Boiler Load Not Met (MBH)	72.	3.	27.	0.	0.	0.	0.	0.
Zone Heating Load Not Met (Btu/1000)	48859.	1352.	1352.	1352.	0.	5127.	13186.	6043
Chiller Output (Btu/1000)	825629.5	525191.2	375171.7	367639.0	268809.8	402177.6	319293.9	[illegible]
Chiller Load Not Met (Btu/1000)	125.	53.	53.	53.	0.	0.	11.	11.
Peak Chiller Load Not Met (MBH)	45.	26.	26.	26.	0.	0.	8.	[illegible]
Zone Cooling Load Not Met (Btu/1000)	0.	0.	0.	0.	0.	0.	0.	[illegible]

cooling. When compared with an identical multi-zone system with dual set-point thermostats, the single set-point thermostat system showed an increase of 30-67 percent in electrical consumption for fans and cooling, depending on the location. Likewise, the gas consumption for heating for the single set-point thermostat system showed a 30-140 percent increase over the gas consumption of the dual set-point system The simulations showed that depending on the location, the total energy consumption of the heating and cooling system is 25-57 percent higher for the multi-zone system with single-point thermostats than for an identical multi-zone system with dual-point thermostats. (See Systems 1 and 2 of Figure 4.)

Data for the multi-zone fan systems with dual-point thermostats and various economy cycles illustrate the effect of the different economy cycles. When compared with the multi-zone system, which has dual-point thermostats and no economy cycle (System 2 of Figure 4), the addition of a temperature economy cycle system caused the electrical consumption for cooling to decrease by 24-68 percent and the gas consumption to increase by 8-29 percent, depending on the location (see Tables 6-9). This increase in gas consumption is a result of the additional heating required during mild or cold weather to warm the mixed air from 55°F to the required delivery-air temperature. Depending on the location, the total energy consumption for the temperature economy cycle system (System 3 of Figure 4) is from 2-6 percent higher than the no economy cycle system. The enthalpy-temperature economy cycle of the multi-zone system has essentially the same effect, although there is a slight decrease in electrical consumption for cooling and in the gas consumption for heating. The net result is that, depending on the location, the total energy required for the enthalpy-temperature economy cycle system (System 4) is 2-5 percent higher than the energy required for a no-economy cycle system.

These results show that if the criterion for selecting an economy cycle for a multi-zone system is total energy consumption, then the "best" multi-zone system is one with no economy cycle. If selection criterion is total power cost, however, the economy cycle may be superior, since electrical power rates are usually considerably higher than unit costs for gas. Choosing an economy cycle will depend on the location, utility rates, and initial cost of the economy cycle system. For example, assuming the electrical cost is \$.03/kwh, and the gas cost is \$.10/therm, the addition of a temperature economy cycle to a multi-zone system with dual-point thermostats and no economy cycle will decrease

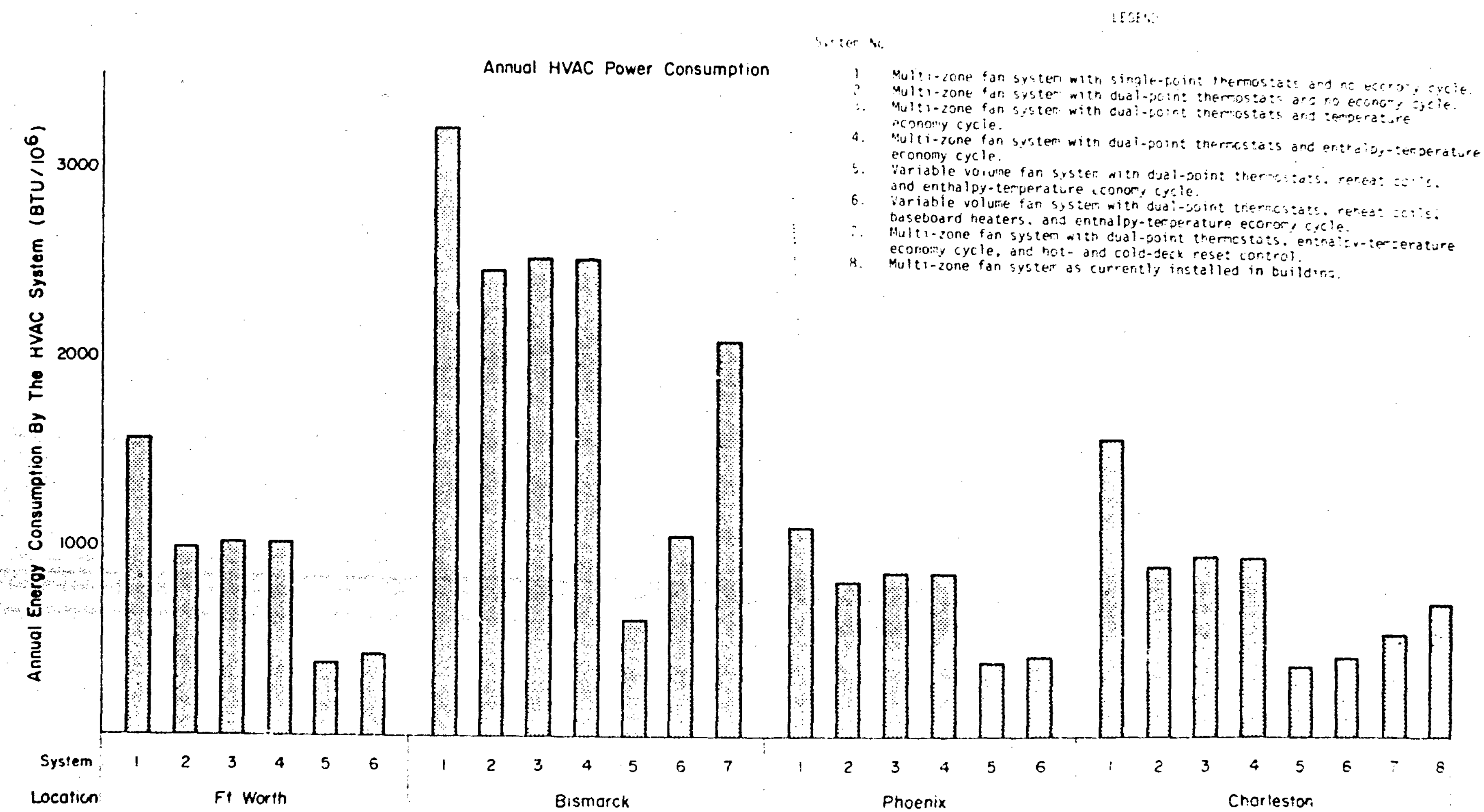


Figure 4. Annual Heating and Cooling System Energy Consumption

total power cost $501 per year in Charleston; addition of an enthalpy-temperature economy cycle will increase the savings by only $33 per year. However, for Fort Worth, the addition of a temperature economy cycle would result in fuel cost savings of $684 per year (using the above utility rates); the addition of an enthalpy-temperature economy cycle would increase savings only $28 annually.

The effect of controlling the hot- and cold-deck temperatures, based on the zones requiring the warmest and coldest air respectively, is shown for Charleston and Bismarck in System 7 of Figure 4. When compared with an identical system having a fixed cold-deck temperature and a fixed hot-deck reset schedule, the multi-zone system with hot- and cold-deck temperature control decreased annual electrical consumption for cooling by 24 percent and annual gas consumption by 55 percent for Charleston data; total annual energy consumption decreased 33 percent when hot- and cold-deck temperature control was added to the system. The same comparisons for Bismarck data show that annual electrical consumption for cooling decreased by 8 percent, annual gas consumption by 20 percent, and annual building power consumption by 17 percent when the hot- and cold-deck temperature control is added. While simulations of this system were not conducted at all locations, the hot- and cold-deck temperature control system appears to significantly reduce overall building power consumption.

Given that the selection criterion is total power cost, the "best" multi-zone system for each location can be determined from the SYSSIM output. For example, using Charleston data and again assuming an average electrical unit cost of $.03/Kwh and an average gas cost of $.10/therm, the total power cost of the building with the multi-zone system having single-point thermostats would be $8765 per year. The multi-zone system with dual-point thermostats and no economy cycle would reduce the buildings total power cost to $6397 per year. The multi-zone system, having a temperature economy cycle and dual-point thermostats, would require a total expenditure of $5896 per year, while the enthalpy-temperature economy cycle system would require $5863. Finally, the multi-zone system modeled with the reset control for hot- and cold-decks would cost $5090 per year. From these calculations, the most energy-conservative multi-zone system modeled for Charleston was the system having dual-point thermostats, an enthalpy-temperature economy cycle, and hot- and cold-deck reset control.

The output for the two variable-volume systems modeled illustrates many of their characteristic advantages and problems. When compared with the multi-zone systems having dual-point thermostats, the variable-volume systems reduced the electrical consumption for fans by approximately 57 percent at all locations. Total power consumed by either variable-volume system appears to be significantly less than that of any multi-zone system at each location; however, careful study reveals that neither variable-volume system as modeled is totally satisfactory. In all locations, the variable-volume system with no baseboard heat met virtually 100 percent of the cooling load and, as expected, did not meet a significant portion of the heating load. The unmet heating load is a result of the minimum air flow during the heating season and the 125°F temperature limit on the supply air to the zone. Most of the heating load was met, but a significant cooling load was not for the variable volume system having baseboard heaters in each zone. The slight unmet heating load for this system resulted from undersized baseboard heaters, while the unmet cooling load resulted from the control scheme used on the baseboard heaters. As modeled for this system, the baseboard heaters function if the outside air temperature is less than 60°F; therefore, they frequently supply more heat than required to a zone, causing a net cooling load. The baseboard heaters may even function when only cooling is required, which causes both heating and cooling loads to be higher than necessary within the zones; this results in unmet cooling loads, usually in the spring, winter, and fall, when the zone's peak cooling demand exceeds the cooling capacity. While results of the simulation studies indicate a relatively small unmet cooling load for the variable volume system having baseboard heat (a system commonly installed in field applications), considerable energy is wasted, because baseboard heaters frequently add unnecessary heat to the space.

Although neither variable volume system, as modeled, appears satisfactory for actual use, an improved system can be described from these results. The new system would be a variable-volume system having baseboard heaters in each zone controlled to operate only when their zones have heating loads which cannot be met by the variable volume system. The total cooling load, as well as the electrical consumption for cooling, would be the same as for the variable-volume system modeled without baseboard heaters, since the two systems would be essentially identical during the cooling season. The total heating load and the total gas consumption would be only slightly less than that for

the variable-volume system modeled with baseboard heaters. While the heaters would function for less time in the new system, their capacities would be slightly greater, causing the load to be approximately the same as the presently modeled system; however, no unmet cooling or heating loads should result. The electrical consumption of the fans in this system would be the same as that for the modeled systems. When compared with the multi-zone system having the smallest annual power consumption for heating and cooling, the improved variable-volume system appears to reduce power consumption for heating and cooling by 25-50 percent, depending on the location. Such large power savings, however, would result chiefly from the reduced amount of ventilation air introduced by the variable-volume system during periods of light or no cooling load. Thus, this system would reduce total energy consumption and total power cost when compared to the modeled multi-zone system, but the amount of ventilation air would be greatly decreased. This reduced ventilation might be acceptable, depending on a building's occupancy and use patterns.

The general characteristics of the system performance outlined here can serve as a guide to selection of the or[illegible]r air-conditioning equipment for a building. The results indicated here are not absolute; for example, in the computer simulation, the single-point thermostat controlled each zone's temperature to exactly 75°F. In actual operation, there would be a slight dead band on the thermostat. Also, the proper system for a particular building would depend on its construction, location, ventilation air requirements, etc. The results shown here, however, do indicate trends which should be applicable for these systems for all types of buildings and locations.

SECTION IX

CONCLUSIONS AND RECOMMENDATIONS

A computer model for predicting hourly building heating and cooling loads and system performance has been achieved. The model is sensitive enough to reflect the impact on energy consumption of most building and system design parameters over which architects and engineers have some control. Specifically, the model permits the building designer to assess the effect of building orientation, size, wall and roof construction, window area, window and wall internal and external shading, insulation, and lighting and equipment loads on building heating and cooling loads. The heating and cooling systems designer can determine the effects of ventilation requirements and equipment sizes on the annual amount of energy consumed. Thus, a degree of optimization in the design of energy-conserving buildings and systems can be achieved by application of the model; its frequent use is strongly recommended.

Certain general conclusions can also be drawn from the test case studies. First, the use of dual-point thermostats and night set-back reduces the building load to one-half or less than that obtained with single-point temperature control.

Second, when typical minimum ventilation rates are specified for the occupied period, ventilation air heating and cooling energy requirements are the largest fraction of the total energy required for heating and cooling. This suggests that considering minimization of the ventilation air supplied is necessary. Exhaust air heat recovery, while not nearly as effective as reduction of ventilation air quantities may also be an economically viable option.

It may also be concluded that while economy cycle systems do not reduce the overall building energy requirements (unless electrical power generating plant efficiency is considered), the energy required for cooling is substantially reduced. The energy consumption difference between temperature and enthalpy control systems, however, is not significant.

Another conclusion resulting from the study is that multi-zone hot- and cold-deck temperatures should be controlled by the zone requiring the most heating or cooling. This approach minimizes "battling" between the hot and cold decks during periods of light load, and consequently, substantially reduces the system energy consumption.

Study results also show that variable volume systems having baseboard heat consume considerably less energy than multi-zone systems. This results largely from the fact that very little ventilation air is introduced during the heating season; in addition, the energy consumed by the fans is less than half that required for multi-zone systems. However, an adequate control scheme must be devised which will prevent the baseboard heating system from operating unless it is required. A simple, thermostatically controlled valve may be a satisfactory solution, although such an application is not currently a standard practice.

Although detailed economic analysis of system options was not part of this study, the brief analysis of potential cost savings shown in Section VIII supports the conclusion that additional first-cost investment in energy-conservative control systems can be amortized in a very short time (one year or less in some cases). Special attention should therefore be given to implementing energy-conservative control methods during the design and construction of new facilities. A large percentage of existing facilities may also be able to incorporate energy-conservative control system modification. Relatively simple changes in current control systems may be more cost- and energy-effective than the addition of insulation and/or storm windows.

SECTION X

REQUIREMENTS FOR FURTHER RESEARCH AND DEVELOPMENT

As indicated in Section I, two significant problems must be resolved before the load-predicting and system simulation program can be widely and frequently used: the large core memory required by the program (140,000 actual words on the CDC 6600 computer) and the lengthy execution time required for full-year building and system simulations (3000 decimal seconds on the CDC 6600 computer). Several recent technological developments, however, suggest that these problems may be solved. One development in particular is the sound basis for computer program development resulting from the FY 75 programming, documentation, and computer model usage efforts previously described. Other developments include new systems software features permitting cataloging of execution times for program subroutines; improved matrix and file manipulation techniques; and new structured programming methods for software development.

It is estimated that application of these technologies to optimize the algorithms, program structure, and computer code will decrease the core requirements of the load profile and system simulation program by 50 percent and reduce the execution time by a factor of five. This will make program execution sufficiently inexpensive to encourage its widespread use.

It is therefore recommended that Phase II of the efforts begun in FY 75 be initiated early in FY 76 to develop a more computationally efficient computer simulation program for calculating building load profiles and equipment performance. This effort should include the following major tasks:

a. Redefining the structure of the program by dividing the calculatory procedures into logical, "testable," and short functional elements.

b. Defining improved algorithms for calculating the required output.

c. Writing and debugging the computer code for the structured program.

d. Revising the program documentation and user manual.

e. Validating the computer program by comparing its output to hourly load and system performance data collected at several buildings.

Phase III of this continuing effort should be testing the program's usability by questioning field architects and design engineers who have used it.

This testing will reveal and allow for early correction of any deficiencies in the program input language, output data, or user manual (the user-program interface).

Before the Phase II program becomes available, the program developed during FY 75 should be used *extensively*. Even though its execution is costly, this cost is a *very small fraction* of what can be consequent savings.

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